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RESEARCHARTICLE

MACROMORPHOLOGICAL AND PHYSICOCHEMICAL CHARACTERIZATION OF AGRICULTURAL SOILSIN ABECHE (EASTERN CHAD)

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ABSTRACT

The main objective of this study was to assess the macromorphological and physicochemical characterization of two types of agricultural soils in the town of Abeche. Thehydromorphic soils and brown steppe soils have been retained. Data collection consisted of taking the surface layers (0-20 cm) of crop fields. The layers were taken using a quartering device. Soil wells have been opened and described. The samples taken are dried, crushed, sievedand packaged. The various analyzes were carried out at the laboratory of the Food Quality Control Center (FQCC) in N'Djamena. The results were compared with reference values. Thesoils studied present a clayey texture in the hydromorphic soil and sandy-loamy in the brown steppe soil. The overall pH results show that the soils in our study area are acidic. Organic matter and exchangeable bases are low. They are lower than the reference values. The total nitrogen contents are within the range of the reference values. The cation exchange capacity is moderately high in hydromorphic soils. It is weak in brown steppe soils. Observed organic matter and nutrient deficiencies can be corrected to achieve potential yield. The use of organic compost, crop rotation and the incorporation of crop residues are possible solutions for maintaining the fertility of agricultural soils in Abéché.

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INTRODUCTION

Agriculture is the most important source of income in Chad. It represents almost a quarter of the gross domestic product (GDP) and employs around 80% of the active population.It thus makes an essential contribution to the economic development of the country. The agricultural sector plays a major role in improving food security. Population growth has led to an increase in the demand for food. Moreover, since the middle of the 20th century, the Sahelianpopulation, which has more than tripled and the ever-increasing number of livestock, must be satisfied while agricultural production is becoming weaker and the rangeland is continually reduced due to the impoverishment of the soil (Ozer *et al*., 2010). The territories of North-East Chad (Ouaddaï, Wadi-Fira and the southern part of Ennedi East and West) are a perfect illustration of this problem (Adey *et al*., 2017). They are subject to climatic hazards, anthropogenic pressure and soil aridity, as is the case throughout the northern Sahel (Favre, 2008). Increasing sustainable food production requires in-depth knowledge of soils, appropriate use of available resources, prevention of degradation and restoration of degraded soils (Basga *et al*., 2018). However, in Chad and in the province of Abéché in particular, in-depth soil knowledge studies are still very unrepresentative. Most of the work is very sketchy and done on a small scale. The current agricultural system has caused soil degradation, and especially the drastic decrease in organic matter levels and the drop in crop yields (Pouya *et al*., 2013; Amonmidé *et al*., 2019). Soils have low fertility, and exported nutrients are not adequately replaced (Kaho *et al*. 2011). The continuous exploitation of the soilleads to a rapid deterioration of its fertility which results in a drop in crop yields (Annabi *et al*., 2009). In the Sahelian zones, the soils are chemically, physically and biologically degraded. Severe limitations have been observed in organic matter and nutrients (Kouli-baly *et al*., 2010).

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Since production is determined by these factors and the relationships between them, it is essential to maintain the rate of organic matter and mineral elements at proportions that can guarantee good land productivity while preserving the soil against any form of degradation. Butno study has been carried out on the agricultural soils of Abéché. Agriculture is the main income-generating activity in the province, particularly the town of Abéché and its surroundings. It is important that the physicochemical parameters are well known for a good use of these soils.

With the problems of climate change, where the rains are badly distributed, it becomes urgent to ensure the maintenance or even the improvement of the qualities of our soils. This is why it is necessary to make an assessment of the characteristics of the agricultural soils of Abéché in order to make recommendations for efficient management. The knowledge soil constituents, their composition and their main physico-chemical properties, constitutes in any event an essential preliminary to the study of the soil environment. It is in this general context that we embarked on this soil study to allow the improvement of agricultural production in order to ensure food security. The main objective of this study is to contribute to the macromorphological study and characterization of the physico-chemical properties of agricultural soils in Abéché with a viewto combating food insecurity.

MATERIALS AND METHODS

Study zone: Capital of the province of Ouaddaï, Abeche has an estimated population of one million inhabitants according to the projection of GCPH2, 2016 with a density of 33 inhabitants/Km^2. Added to this are Sudanese refugees 103,017 people (Adey *et al*., 2018). The main activities ofthe province of Ouaddaï are agriculture and animal husbandry which take place in the unfavorable conditions. The climate is of the Sahelian type, the rainfall is between 200 and 400 mm / year. The temperature is around 28°C to 42°C. It is located in the Sahelian zone of Chad. It recorded an average cumulative rainfall of 485.6 mm. However, it is experiencing a worrying situation of food and nutritional insecurity and the prevalence of malnutrition exceeding the WHO emergency threshold (15%) (WHO, 2007).

Location of study sites: The Bagarine and Arkou sites are respectively located approximately 3 km and 5 km from the town of Abéché. The Bagarine site is located between 13°51'900 North latitude and 20°41'081 East longitude. The Arkou site is located between 13°52’160 North latitude and 20°51’150 North latitude East longitude (Figure 1).

FIELD METHODSSAMPLING

Sampling of surface horizons: The surface and depth samples were taken in the agricultural areas of Bagarine and Arkou. The samples were taken from a thickness of 0 and 20 cm. Composite sampling consisted of systematically taking soil from the perimeters and diagonals of the plots in order to obtain arepresentative mixture of the latter. At each sampling point, about 1 kg of soil was taken. Intotal, several kilograms of soil were sampled and transported to the Geology Laboratory of Adam Barka University in Abéché.

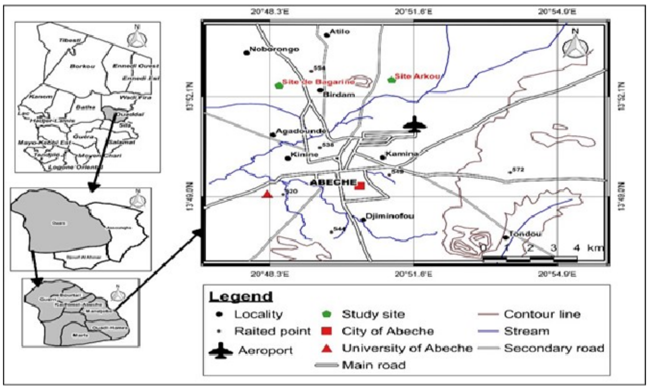

Figure 1. Location map of the study site (source: Hamadou 2019)

Sampling of depth horizons: Two soil wells were drilled in the agricultural areas of Abéché. The geographical coordinates taken by the GPS receiver are respectively 013°51.926' North latitude; 020°49.077' longitude East and altitude 539 m with an accuracy of ± 3 m. The different horizons of these soil wells have been identified and described according to the following parameters: texture, structure, color, pores or voids, presence of organic matter, presence of roots, presence of stains, presenceof microorganisms, presence of rock fragments, etc. All the samples taken from the crop horizons and depths were pretreated.

Sample preparation

The preparation of the samples is a step which consisted in carrying out in turn (Afnor, 1992.NF X 31-147):

Figure 2. Realizations of soil pits ofbrown steppe soils

Figure 3. Achievements of soil pits ofhydromorphic soils

- **Drying:** this is done in the open air, at ambient laboratory temperature and then in an ovenat 105°C for 24 hours.
- **Grinding:** this involved reducing the samples to a fine powder, so as to bring the elements to be analyzed into solution. It was carried out using a porcelain mortar and pestle (Appendix 2).
- **Sieving:** it consists of the elimination of solid fragments larger than 2 mm which are not usually considered to be part of the soil; it was carried out using a 2 mm mesh sieve. Soil analyzes were carried out according to standard laboratory procedures. In the laboratory, each sample was then crumbled and sieved.

LABORATORY METHODS

Determination of the physico-chemical parameters of agricultural soils in Abéché. The samples were packaged in plastic bags at the Geology Laboratory of Adam Barka University in Abéché and sent to the laboratory of the Food Quality Control Center (CECOQDA) in N'Djamena for physico-chemical analyses. The results of analyzes of these soils were compared with results of previous work. The analyzes were mainly carried out on the particle size, the determination of the pH values, the MO, the nitrogen levels, the cation exchange capacity, the electrical conductivity and the exchangeable bases. The particle size was determined by following standard NF X31-107 75 (Buol *et al.*, 2011).

The fractionation protocol thus implementing two complementary methods (dry fractionation up to 80 µm then gravimetric separation up to 2 µm by particle sedimentation (according to the Stockes law). The classification of soil textures was carried out according to the USDA texturediagram Measurement of soil pH was carried out according to the method described by Mathieu and Pieltain (2003). The measurement consisted of putting 10 g of sieved soil in contact with 25 ml of distilled water. Then the mixture was stirred with a glass rod and allowed to stand before the pH meter reading. For the determination of the OM, the method of loss on ignition by calcination in the oven was used. 10 g of previously dried soil were taken and incinerated in a Nabertherm brand oven at 550°C for 2 hours (Mwamburi, 2003). In addition, the method for determining electrical conductivity consists of preparing a suspension of 25g of soil in 100mL of distilled water. After having stirred for, the solution obtained is left to stand for at least 24 hours. Conductivity was measured using a HANNA HI brand conductivity meter. Cation exchange capacity CEC refers to the ability of soil to retain and exchange nutrients readily available to plants.

It was determined according to the standardized AFNOR NFX 31 – 130 methods (Saragoni *et al.*, 1992). The analysis of total nitrogen was determined by standard NF ISO 13878. The content of major elements: $Ca2+$, $Mg2+$, $Na+$ and $K+$ was determined by the ammonium acetate percolation method Arkou

RESULTS

Results of some soil physico-chemical parameters: The results relating to particle size, descriptions of soil profiles, pH, organic matter, conductivity, residual moisture, exchangeable bases and cation exchange capacity (CEC) are shown in Figures 4, 6, 7, 8, 9 and 10:

Matrices and correlation circles of the parameters studied: The Pearson correlation matrices made it possible to establish the correlations between the physico-chemical parameters studied ($P < 0.05$). The results are shown in Figures 11 and 12.

DISCUSSION

MACROMORPHOLOGICAL DESCRIPTION OF SOIL WELLS

Profile of Bagarine: This profile was produced in the market gardening area of Bagarine Figure 2. The geographical coordinates taken by the GPS receiver are as follows: 013°51.926' North latitude; 020°49.077' longitude East and altitude 539 m with an accuracy of ± 3 m. The depth of this well is 149 cm and presents from top to bottom the following succession:

0 - 10 cm: Horizon 1 (H1): brown in the dry state with very rare fine roots, sandy-loamy clay, very compact polyhedral structure, the presence of microorganisms is noted in this horizon. There are a few galleries of living beings. The transition to the lower horizon is gradual.

10 - 48 cm: Horizon 2 (H2): brown in the dry state with low biological activity, sandy-loamy clay, medium blocky structure and very little knife action. Note the presence of pores and a few rock nodules in this horizon. Its boundary with the underlying horizon is sharp.

48 - 92 cm: Horizon 3 (H3): reddish brown when dry, sandy-loamy-clayey, medium polyhedral, very compact with the presence of microorganisms, fine roots and hard nodules. There is a cleartransition in this horizon.

92 – 149 cm: Horizon 4 (H4): pale brown in the dry state, sandy-clayey, very compact polyhedral structure, we note the presence of granitic rock and fragments of quartz. The transition with the parent rock is clear.

Arkou site profile: This profile is 149 cm deep and was opened in a market garden area of Arkou Figure 2. Its geographical coordinates are as follows: 13°52.167' North latitude; 20°51.140' East longitude and 537 m altitude. The profile has five (05) horizons whose succession from top to bottom is as follows:

0 - 25 cm: Horizon 1 (H1): brown, sandy-clayey, polyhedral structure with the presence of roots and microorganisms. We note the presence of many galleries where living beings live. Not very compact in the knife test. Abundance of biological activity. The transition with the underlyinghorizon is gradual.
25 - 35 cm: Horizon 2 (H2): brown, sandy, particulate structure with the presence of a few rareroots. There is an abundance of gallery of living beings and not very compact. The boundary with the lower horizon is clear.

35 - 155 cm: Horizon 3 (H3): gray when wet, clayey, polyhedral structure with the presence ofa few rare roots and very compact.

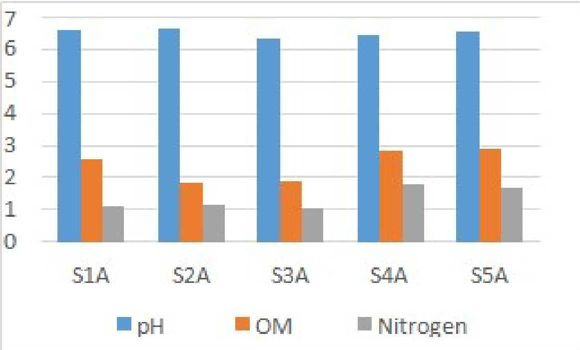

Figure 4. pH, OM and Nitrogen ofhydromorphic soils of Arkou

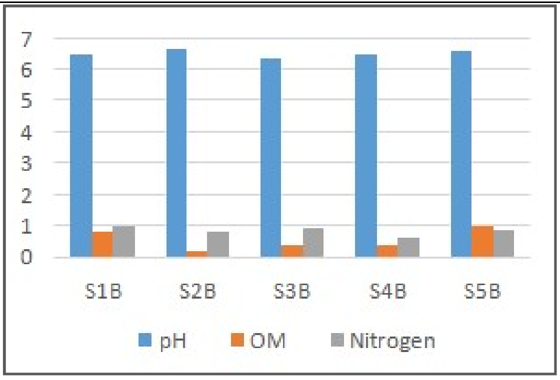

Figure 5. pH, OM and Nitrogen of hydromorphic soils of Bagarine

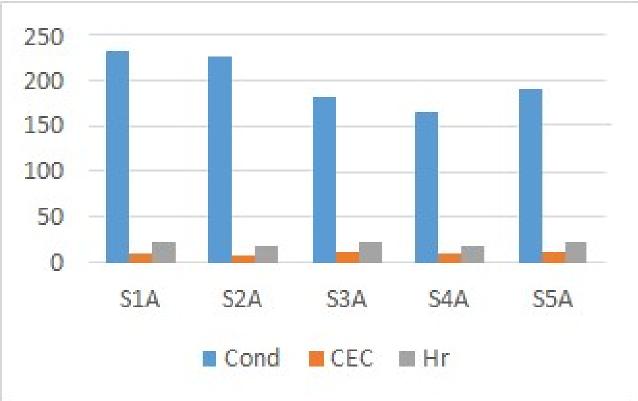

Figure 6. Cond, CEC, and Hr of hydromorphic soils of Arkou

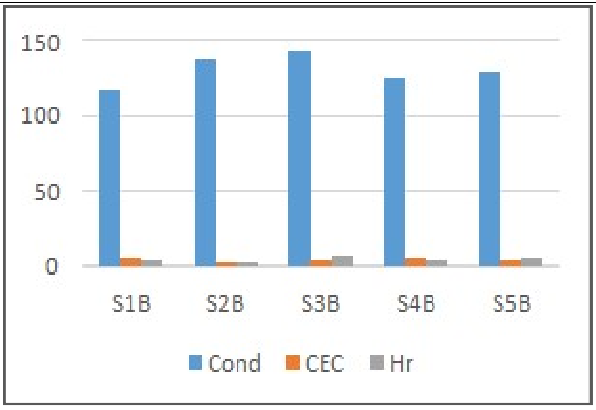

Figure 7. Cond, CEC, and Hr of brown steppe soils in Bagarine

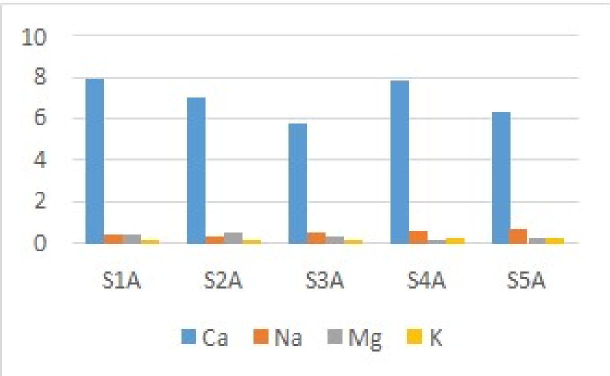

Figure 8. Ca2+, Na2+, Mg2+ and K+ of hydromorphic soils of Arkou

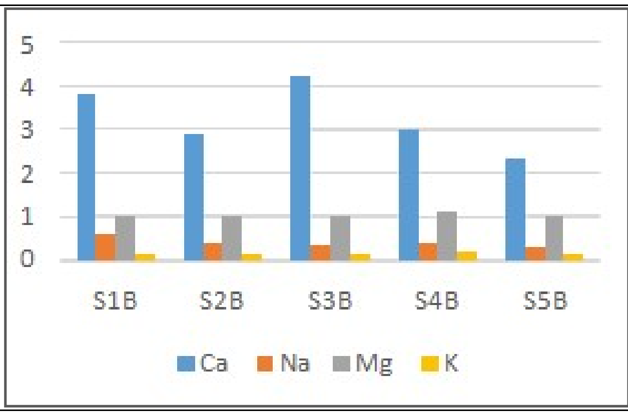

Figure 9. Ca2+, Na2+, Mg2+ and K+ of brown steppe soils in Bagarine

Microbial life is reduced in this horizon. Presence of a fewrare galleries of earthworms. The transition is gradual with the underlying horizon.

155 - 191 cm: Horizon 4 (H4): brown when wet, sandy-clayey, particulate structure and not very compact. The presence of microorganisms is noted and the transition is clear.

191 - 241 cm: Horizon 5 (H5): brown when wet, sandy, particulate structure, porous and not very compact. The presence of microorganisms is noted and the transition is clear. The lower set has yellow spots. These traces would reflect the hydromorphy and would be linked to the temporary stay in

It contains reddish brown to pale brown horizons. The texture is sandy-loamy-clayey throughout the profile. The structure is polyhedralfrom the surface to the depth. On the other hand, the pedological profile of the hydromorphic soils of Abéché is 241 cm thick with a color that varies from brown to gray in the humid state at depth.

The texture is clayey-sandy on the surface and clayey when going deeper. The structure is particulate. We note the presence of some microorganisms in the surface and deep horizons.

CHARACTERIZATION OF THE PHYSICOCHEMICAL PARAMETERS OF SOIL

Particle size analysis: The grain size analysis (Table 2) shows the dominance of the sandy fraction in the brown steppesoils of Bagarine.

From a quantitative point of view, these soils are the richest in sandy fractionwith a rate of 81.80%, followed by 14.80% for the silty fraction and finally 3.80% of the clay fraction. The texture of the brown steppe soils of Bagarine is sandy-blue to sandy-loamy (Figure6). On the other hand, Figure 6 shows the dominance of the clay fraction in the hydromorphic soils of Arkou.

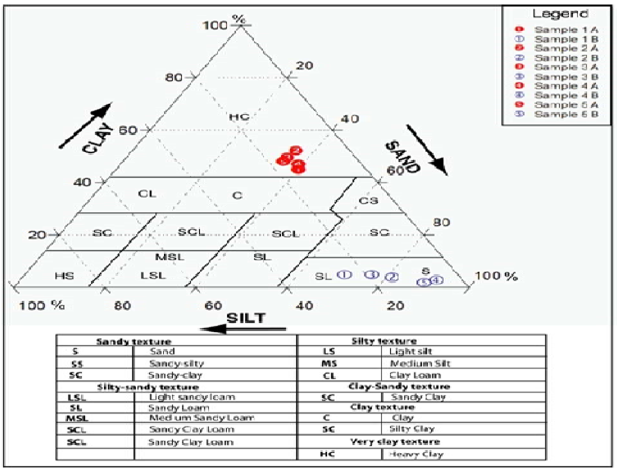

Figure 10. Diagram of brown steppe and hydromorphicsoils textures in Bagarine and Arkou

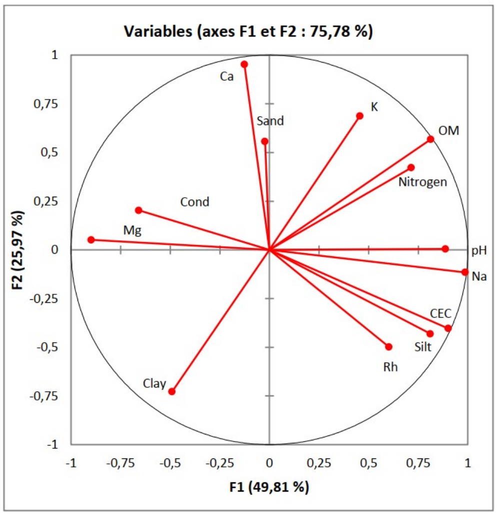

Figure 11. Correlation circle between the physico-chemical parameters of hydromorphic

From a quantitative point of view, these soils are richer in clay fraction with anaverage of 48.80%, 37.40% sand and 14.80% on average silt. The texture of the hydromorphicsoils of Arkou is clayey to clayey-sandy (Figure: 6). These results show that the brown steppe soils of Abéché have a cultural suitability for food crops. Pearl millet and rainfed sorghum are the main staples of the city of Abéché. Added to this are oilseeds (peanuts) and beans. In addition, the hydromorphic soils of our study area are soils suitable for market gardening practiced around the city.

Organic Matter, pH and Nitrogen: The results in Figures 3 and 4 show that the organic matter content varies from one soil to another and from one sampling point to another. The organic matter contents of the brown steppe soils of Bagarine studied vary between 0.10% and 0.42% (with an average of 0.23%), these contents are lower than those of the hydromorphic soils of Arkou which vary from 0 .90 to 1.87 (with an average of 1.27).

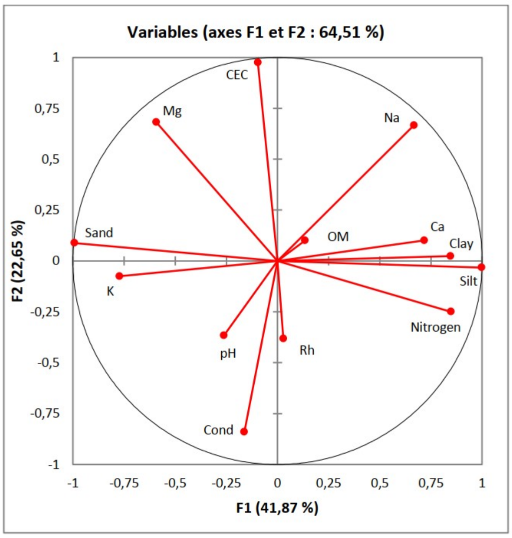

Figure 12. Correlation circle between the physico-chemical parameters of brown steppe

The levels of organic matter in the soils studied are lower than the reference values (3.5% to 6.5%). The low OM contents would reflect on the one hand their vegetation which would not produce a significant plant biomass (Pallo, *et al*. 2006), on the other hand the long duration of the dry season which increases the rate of undecomposed matter(Dabin , 1985). The presence of organic matter in the soil is at the origin of the appearance of physicochemical properties favoring the development of cultivated or natural plants. The increase in the contents is accompanied by an improvement in the structure, the ease of water infiltration, the increase in the water retention capacity, as well as the power of resistance to erosion. (Ben Hassine *et al*., 2008). The good structuring of the soil and the stability of the aggregates depends on the quantity and quality of the OM which allows the flocculation of the clay minerals, a suitable condition for the aggregation of the particles (Tedjada and Gonzalez, 2006).

The percentages of nitrogen levels in our study area are presented in Figures 3 and 4; and vary from 1.03% to 1.78% with an average of 1.33%) in hydromorphic soils; and 0.62% to 1.01%with an average of 0.84%. The total nitrogen content is within the range of reference values between 1.22% to 2.22%. Our results are similar to the values obtained by (C. S. A. Ballot *et al*, 2016). Moreover, in brown steppe soils, the total nitrogen content is very low. They are substandard. Sandy soils, poor in total nitrogen and have a low proportion of exchangeable bases and organic matter. According to (Duchaufour *et al* 2001), soils characterized by a variable grain size but always predominantly sandy (around 40 to 60%). The results of the pH measurements of our study area vary from 6.10 to 6.65 (with an average of 6.35) in the steppe soils of Bagarine and from 6.32 to 6.52 (with an average of 6.41) in the hydromorphic soils of Arkou. The overall pH results show that the soils in our study area are acidic. This acid character reflects the geological nature of the study area, dominated by graniticrocks (Barkai *et al* 2014). The pH directly influences the assimilability of nutrients by the plant cover and as such plays a fundamental role in the profitability of the crop (Gadras, 2000). The highest pH value was recorded at SB12 probably due to the presence of soil organic compounds present in the residues of anthropogenic activities, which increases soil pH values (Dolezalova *et al*; 2015).

Electrical conductivity, Residual humidity and C.E.C.: Electrical conductivity can be defined as the amount of total dissolved salts (Singare, 2010). It is an easy and reliable indicator of soil quality (Johnson *et al*. 2005). Figures 9 and 10 show that the sampling points with the highest electrical conductivities are SA1 with 233 µS/cm (with anaverage of 199 µS/cm) at the hydromorphic soil level of Arkou; and SB3 with 142 µS/cm (with an average of 130 µS/cm) in brown steppe soils. Overall, the electrical conductivity values of different soil types are therefore favorable for agriculture. Indeed, when the electrical conductivity is high, there are few problems related to salinity (Oumar and al, 2014). The overall conductivity results show that the hydromorphic soil of Arkou is more conductive thanthe steppe soil of Bagarine. In view of the results obtained, we note that the residual humidity varies from 17.00 to 22.40% (with an average of 20.21%) in the hydromorphic soils of Arkou; and from 3.00 to 6.40% (withan average of 4.55) in the steppe soils of Bagarine.

The wettest sampling points are respectivelySA3 (22.40%) and SB5 (6.40%) for the hydromorphic soil of Arkou and the steppe soil of Bagarine respectively. The high residual moisture content would promote the solubility, mobility and even the bioavailability of heavy metals present in the soil (Noubissié *et al*. 2008).Cation exchange capacity (CEC) refers to the ability of soil to hold and exchange nutrients readily available to plants. In hydromorphic soil, it is between 8 and 11.3 meq/100 (with an average of 10.03 meq/100). On the other hand, the CEC values oscillate between 2.89 meq/100and 5.25 meq/100 (with an average of 3.88 meq/100). The cation exchange capacity is moderately high (with 10.03 meq/100) in hydromorphic soils; and low (with 3.88 meq/100) in brown steppe soils. The brown steppe soils of Abéché have a low cation exchange capacity compared to the critical threshold (9 ≤ CEC ≤ 12 cmol+/kg-1) compared to hydromorphic soils.Our results obtained from all of our two study soils are similar to those obtained by (Buol *et al*,2016).

Exchangeable bases: The proportions of exchangeable bases in the hydromorphic soils of Arkou have an average of6.96% calcium; .031% on average magnesium; 0.52% sodium and 0.16% potassium on average(Figure 1). On the other hand, in the brown steppe soils of Bagarine the levels of exchangeable cations are relatively low. These soils have an average of 3.25% calcium; 1.03% on average magnesium, 0.41% on average sodium and 0.14% on average potassium. Despite its importance for the majority of plants, potassium shows low levels in both types of soil. The sodium contentsare very low in the brown steppe soils of Bagarine with an average of 0.41% on average and inexcess in the hydromorphic soils of Arkou, with an average of 0.52%. This last element becomes harmful when it is in excess. It is important to emphasize that the basic cations (Ca2+, Mg2+, K+) play a role in the study of the absorbing complex and in the phenomena of cation exchange (Duchaufour, 2001). They not only act as nutrients but play an essential role in neutralizing acidity, maintaining biological activity and structuring the soil.

STATISTICAL ANALYSIS

The Pearson correlation matrices made it possible to establish the correlations between the physico-chemical parameters studied (P 0.05). Figure 7 presents the Pearson correlation matrix between the physico-chemical parameters of hydromorphic soils. We observe a positive and very significant correlation between silt/CEC, Silt/Hr, Cond/Mg and CEC/Na. In addition, the correlations are positive and significant between silt/pH, silt/Na, pH/MO and pH/CEC, pH/Na MO/Nitrogen, MO/Na, MO/K, Nitrogen/Na, Nitrogen/K and CEC /hr. As for Figure 8, it presents the Pearson correlation matrix between the physico-chemical parameters of brown steppe soils. We observe a single positive and very significant correlation between clay/Ca. On the other hand, the correlations are positive and significant between sand/K, silt/clay, silt/nitrogen, silt/Ca and CEC/Mg. Moreover, the correlations are moderately positive and significant between sand/Mg, silt/Na and Mg/K. Figures 7 and 8 show the circles of correlations observed in the hydromorphic and steppe soils of Arkou and Bagarine respectively.

CONCLUSION

Abeche is one of the major agricultural regions of Chad. It is characterized by two major types of agricultural soils (hydromorphic soils, brown steppe soils). In this work, we carried out a macromorphological study and physicochemical characterizations of these two types of agricultural soils of Abeche. Two sites were studied (Bagarine and Arkou). The soils studied on the surface (0-20 cm) have a sandy to sandy-loamy texture in the brown steppe soil and clay in the hydromorphic soil. The overall pH results show that the soils are acidic. This acid character reflects the geological nature of the study area, dominated by granitic rocks. They arerelatively low in organic matter. The nutrient balance reveals deficiencies in exchangeable bases. The contents of organic matter, nitrogen in brown steppe soils, and exchangeable bases are not sufficient to optimize crop yield. The use of fertilizers is essential and important to obtain a potential yield. In addition, the use of compost, crop rotation and the incorporation of crop residues are possible solutions for maintaining the fertility of agricultural soils in Abeche.

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